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Heat Pipe Methanator**

by

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CONCEPTUAL DESIGN OF A HEAT PIPE METHANATOR

by

W. A. Ranken

ABSTRACT

A conceptual design of a unit for converting synthesis gas from coal to methane is described. Gravity-return heat pipes are used in a simple configuration that provides for removing the reaction heat from the methanation-promoting catalyst, transmitting a portion of this heat to an incoming-gas preheat section, and delivering the remainder to a steam generation unit. Problems peculiar to the use of heat pipes for this purpose are considered, and methods for solving or circumventing these problems are discussed.



I. INTRODUCTION

Virtually all processes for making synthetic natural gas from coal include a step for upgrading the raw product gas to a high Btu pipeline quality gas. This is done by using the shift reaction to increase the hydrogen-carbon monoxide ratio in the raw gas to 3.0:3.1, then passing this mixture through a catalyst bed where it reacts exothermally to give a nominal yield of $\text{CH}_4 + \text{H}_2\text{O}$.

A major problem in the design of methanator units is the removal of heat from the catalyst bed. If the catalyst temperature is not held within relatively narrow limits, the poisoning rate tends to rise sharply and catalyst lifetime is markedly reduced. An even more serious consequence of inadequate heat removal is the formation of hot spots, which can propagate and rapidly destroy the effectiveness of the catalyst bed.

One method for cooling methanator catalyst beds is to use the heat capacity of the reacting mixture to remove the reaction heat. The gas is recycled through the methanator about 12 to 20 times with heat removed in the recycle loop.¹ An alternative method is to place the catalyst, in pellet form, in tubes that pass through a vat of Dowtherm A heat transfer fluid. The reacting gas mixture flows through the

tubes and by conduction and convection transfers the heat from the catalyst pellets to the tube wall and then to the boiling Dowtherm A. Cooling in this manner is insufficient if the tube diameter exceeds about 12 mm; therefore, an exceptionally large number of tubes is required for a methanator of this design.

A third cooling method is that used in the Tube Wall Reactor (TWR), which is being developed at the Pittsburgh Energy Research Center (PERC) of the U.S. Bureau of Mines.²⁻⁴ As originally conceived, this design consisted of vertical reentrant tubes whose exterior was coated with flame-sprayed Raney nickel catalyst to a thickness of ~ 0.5 mm. Heat generated by the reacting gas mixture flowing along an array of such tubes was removed by boiling Dowtherm A. The boiling Dowtherm A was introduced into each reentrant tube by gravity flow through the inner tube of the concentric pair and flowed up the annulus between the two tubes. Temperature was controlled by using an inert gas overpressure to control the Dowtherm A boiling point. This design was deemed impractical when it became apparent that catalyst changes would be required two or three times a year and each of the reentrant tubes would have to be removable (so that the depleted catalyst could be taken off by sandblasting and fresh catalyst applied by flame

spraying). This required the use of many relatively large (~60-mm-i.d.) high-pressure flanges, which would be exceedingly difficult to put in the available space and would be subject to leakage. Because the anticipated gas pressure and reaction temperature would be 6.9 MPa (1000 psi) and 672 K (750°F), respectively, the latter could pose a difficult problem.

To eliminate the necessity of flanging each tube, the TWR design was modified so that it was essentially the same as the tube-in-Dowtherm-vat described above, except that the Raney nickel catalyst is applied by flame spraying the inner wall of the 60-mm-o.d. tubes. Because the catalyst is in direct contact with the tube wall, diameters of this magnitude are acceptable. Because catalyst removal and reapplication can be done in place, the tubes can be permanently welded to the end plates of the methanator. However, flame spraying the inner wall of the tube requires a special small, rotating flame-spray head. Application rates are currently about 300 mm/h (1 ft/h). Considering that the tube lengths are 9 m (30 ft), replacing the catalyst in a bundle containing as many as 1200 tubes will be an imposing, time-consuming operation for this type of design.

In subsequent sections of this report a methanator design is discussed that takes advantage of the self-contained heat transfer capability of the heat pipe to yield a version of the TWR with the following features:

- Simple configuration combining catalyst bed, incoming gas preheat section, and thermal recovery.
- Easy replaceability of catalyst.
- Short downtime for catalyst replacement.
- Lack of requirement for a multiplicity of large, leak-prone, high-pressure seals.
- Redundancy of operation. (Failure of one heat transfer component does not shut down the whole system.)
- Low inventory of heat transfer fluid.

II. HEAT PIPE METHANATOR REFERENCE DESIGN

A schematic representation of the Heat Pipe Methanator (HPM) is shown in Fig. 1. It consists of an array of gravity-return heat pipes enclosed in a pressure shell in a manner that provides for methanation with (1) low temperature drop (ΔT) catalyst cooling, (2) preheating of the inlet gas stream, and (3) recovery of the reaction heat by a steam-generating heat exchanger, all in a single unit. The heat pipes are supported by a grid plate at the

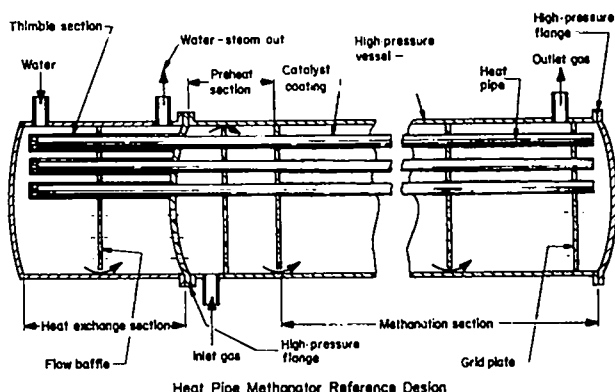


Fig. 1.

Schematic representation of the HPM showing the unification of methanator, preheater, and steam generator into one unit. In operation, the heat exchanger would be tilted several degrees above horizontal to enhance gravity return of the heat pipe working fluid.

right-hand side of the unit. At the other end of the methanator chamber, the heat pipes are slip-fit into a multithimble configuration, which provides the heat transfer surface for the thermal recovery heat exchanger. The latter is a separate chamber at the left-hand side of the unit. Flow baffles are placed in both chambers to establish either a uniform flow distribution or a multipass cross flow configuration.

In the methanation side of the unit, incoming gas passes through the preheat section reaching a temperature of about 650 K (~700°F) at which the methanation reaction will take place at the desired rate. At this point it passes into the methanating section. The main difference between the two sections is that in the preheat section the heat pipes are roughened to facilitate heat transfer, and in the methanation section they are coated with a catalyst (probably, but not necessarily, by flame spraying).

In operation, heat is generated by the methanation reaction along the catalyst-coated section of the heat pipes. This section represents approximately two-thirds of the total heat pipe length because heat input is limited to about 13 kW/m² by the reaction rate. The reaction heat vaporizes the working fluid of the heat pipes and is transmitted by vapor flow toward the heat exchanger. Approximately one-fourth of the total heat is deposited by vapor condensation in the preheat section, bringing the incoming gas up to temperature, and the remainder is delivered to the heat exchanger. In each heat pipe the condensed vapor is returned by gravity flow in a baffled flow channel to the catalyst-coated section of the pipe.

Heat transfer in the heat exchanger occurs by conduction through the annular gas gaps between the heat pipes and the interior walls of the thimbles. The sizing of this gap depends on the temperature desired in the heat exchanger, as well as the steady-state composition of the gas mixture in the gap and the length of the heat exchanger thimbles. It will probably be in the 0.1- to 0.2-mm range, so that insertion and removal of the heat pipes should not be difficult.

The dimensions of the methanator unit will depend on cost-effectiveness considerations involving vessel pressure, pressure vessel wall thickness, thimble wall thickness, optimum heat pipe spacing, heat pipe wall thickness, thimble grid thickness, end cover flange design, heat pipe performance limits (depending on working fluid choice, condensate flow baffle design, and tilt angle), catalyst performance, and other similar design parameters. The following estimates represent a reasonable point of departure.

An individual methanator unit might consist of a pressure vessel about 1.2 m in diameter and just over 11 m in length, containing 500 heat pipes 51 mm in diameter in a hexagonal array having a 60-mm pitch. The heat pipe length will be approximately 11 m, 8 m of which are catalyst coated. Such a unit would have a total catalyst surface area of about 650 m². Current values for the 3 H₂ + CO reaction rate are 3.6 × 10⁻³ m³/s/m² of catalyst surface area at a pressure of 6.89 × 10⁶ Pa (1000 psi) and a reaction temperature of 670 K. Thus, this size methanator would produce 2.3 m³/s of methane or 7.1 × 10⁶ ft³/day. Therefore, a 250 × 10⁶ ft³/day methanation plant would require 35 methanator units.

III. HEAT PIPE DESIGN CONSIDERATIONS

As indicated above, the reference design heat pipe is 51-mm o.d. with an 8-m-long catalyst-coated section. For a nominal wall thickness of 2 mm, the internal area available for vapor flow and condensate return is 1734 mm² (2.7 in.²). Allowing 20% of the area for condensate return yields a vapor flow passage area of 1400 mm². The reaction heat from the conversion of 3 H₂ + CO to methane is 2.4 MJ/m³ STP, resulting in a thermal power generation rate of 200 MW for a 250 × 10⁶ ft³/day methanation plant. From the numbers given in Sec. II, it is apparent that the thermal load on each heat pipe is only 11.4 kW or 8.1 MW/m². Figure 2 shows the ultimate performance limits of Dowtherm A, mercury, cesium, and potassium in the temperature range of interest

for the methanation reaction. This limit, called the sonic limit, is fundamental because it is established by the limitation on the rate of vapor flow to sonic velocity. There are other limits, such as liquid return rate and vapor-liquid counterflow interaction, but these can be dealt with by changing the liquid inventory and the heat pipe tilt angle, or by using flow baffles. The curves in Fig. 2 show why Dowtherm A and mercury are the most desirable working fluids from a performance standpoint. However, cesium and potassium are potential candidates for methanators operating near the upper bound of the acceptable methanation reaction temperature range (shown by the vertical dashed lines in Fig. 2).

The force of gravity is used to return the condensed working fluid to the evaporator section (catalyst-coated section) of the heat pipe. Because this return flow is inhibited by the interaction with vapor flowing in the opposite direction, the heat pipe performance can be improved by providing baffled channels for this return flow. Figure 3 shows cross-sectional views

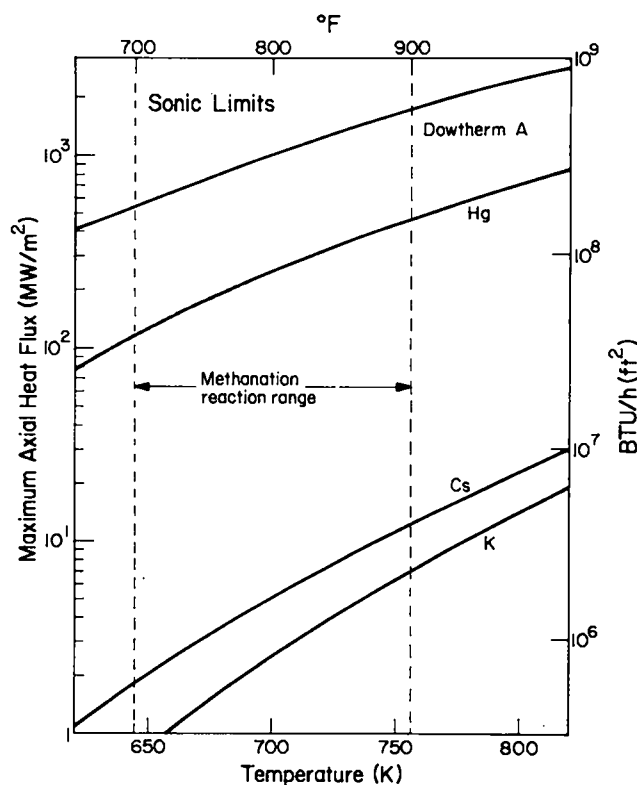
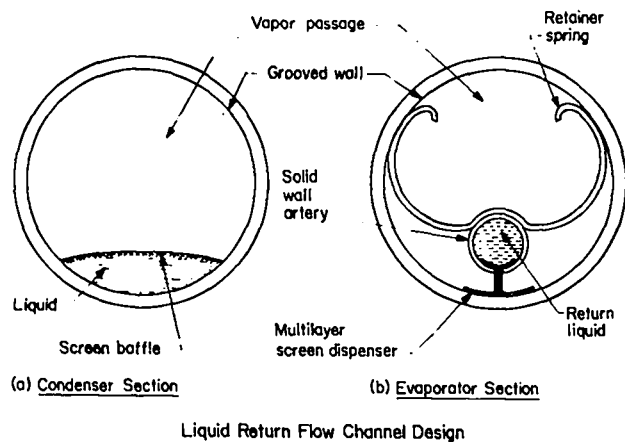


Fig. 2. Sonic performance limits of commercially available heat pipe working fluids of potential suitability for the methanator application.



Liquid Return Flow Channel Design

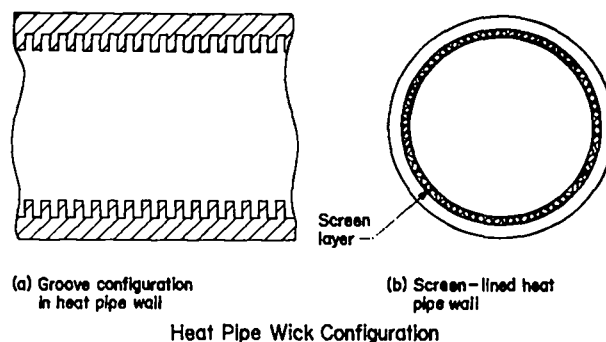
Fig. 3.

Cross-sectional views of the reference design methanator heat pipe for the (a) condenser section and (b) evaporator section.

of the reference design heat pipe for the condenser and evaporator sections. In the condenser section (Fig. 3a), vapor condensing on the tube wall flows to the bottom of the tube and proceeds along the bottom by what is termed "puddle flow" to a transition region where it is diverted into the pedestal artery configuration shown in Fig. 3b. A screen baffle is placed at the bottom of the tube in the condenser section to reduce the vapor-liquid counterflow interaction and yet not interfere with the circumferential flow of condensed liquid to the bottom of the tube. The puddle flow at the bottom of the tube somewhat reduces the effective heat transfer area, but this is offset by the simplicity of the configuration.

The artery in the evaporator section of the heat pipe is a solid wall tube with a slot in the bottom where several layers of fine mesh screen are crimped. The tube wall shields the liquid returning from the condenser from direct interaction with the oppositely moving vapor stream. The screen serves to dispense the returning liquid to the evaporator tube wall capillary structure and also helps to minimize heat flow from the tube wall to the artery. Some degree of thermal isolation of the liquid in the artery is required to restrict the formation of vapor in the artery and prevent appreciable vapor flow up the artery with its consequent restrictive effect on the return liquid flow.

The inner wall of the reference design heat pipe is circumferentially grooved as shown in Fig. 4a. These grooves are about 0.1 mm across and 0.3 mm deep and have the function, in the evaporator, of dis-



Heat Pipe Wick Configuration

Fig. 4.

Configuration of capillary systems that provide circumferential distribution of the heat pipe working fluid: (a) spiral grooved configuration and (b) screen lining.

tributing liquid from the artery to the entire inside surface of the heat pipe. In the condenser section their main purpose is to increase the effective heat transfer area. This occurs because capillary forces tend to draw the condensate to the bottom of the grooves and prevent the buildup of a low conductivity film on the entire collector surface. Optimum groove dimensions and configurations have not been determined for the condenser section, but they may well differ from the evaporator grooves because circumferential capillary pumping action is not a requirement.

An alternative method of circumferentially distributing the liquid in the evaporator is to line the inner wall with one or two layers of screen as shown in Fig. 4b. This can be done by inserting a screen tube into the pipe and drawing one or more tapered plugs through the pipe to push the screen against the wall. Because this method does not assure the direct thermal contact of the capillary structure with the tube wall that occurs with the groove system, vapor bubble formation between the screen and the heat pipe wall could be a problem. However, with the low heat input rates occurring in the methanator application, bubble formation is not expected to be a problem and the screen alternative should be feasible. The method actually selected will largely depend on the choice of heat pipe wall material and working fluid.

Although a heat pipe with the specific artery design described here has not been constructed, heat pipes of similar design have been built. One version has found commercial application in thermal recovery units for buildings where a high air-change rate is required. The National Science Foundation

(NSF) is sponsoring development work on a water heat pipe of this general type that operates at 575 K (576°F) for use in collecting and transmitting solar energy focused on it by a parabolic trough-type reflector. Calculations done at the Los Alamos Scientific Laboratory (LASL) on a Dowtherm A heat pipe for this purpose indicate that this gravity-return type of design can transmit 25 kW of thermal energy flow at 575 K in a 12-m-long pipe with a 51-mm o.d. if the tilt angle is 0.4° and an artery with a cross-sectional area of 150 mm² (0.25 in.²) is used to return the condensate liquid without vapor-liquid counterflow restriction.

Temperature control of the heat pipe is achieved by adding inert gas and by providing a region at the condenser end where the heat deposition rate increases rapidly with axial distance. This is the main reason for having the heat exchanger water inlet at the condenser ends of the heat pipes. In operation, the working fluid vapor pumps the inert gas to the condenser end of the heat pipe where a vapor-inert gas interface is established. The volume occupied by the inert gas decreases or increases as the input heat increases or decreases, respectively (with more or less heat transfer area being required to dump the heat transmitted to the heat exchanger). Volume changes result in inverse changes of pressure, establishing the vapor pressure of the working fluid and therefore its operating temperature. Because the vapor pressure of the fluid generally increases rapidly with temperature, relatively large pressure variation can occur without causing undue change in operating temperature. The temperature can be varied by changing the quantity of inert gas added to the heat pipe. The desired heat removal profile for establishing temperature control can be obtained by varying the heat pipe to thimble wall gap thickness, a subject discussed further in Sec. IV.A.

Final determination of the choice of working fluid for the methanator heat pipe will depend on a number of factors requiring further evaluation. From a standpoint of fluid cost, Dowtherm A is the preferred choice, just as it is the choice for the cooling liquid in more conventional TWR designs. However, this material is being pushed to its thermal stability limit in the methanator application, and degradation will be a problem requiring compensatory action (see Sec. IV.C).

The selection of mercury as a working fluid leads to a higher initial cost and presents the need for special treatment of the heat pipe wicking surfaces to promote wetting.⁵ Because of the high cost of mercury, the limited working fluid inventory required for the heat pipe is advantageous. The use of mercury for nonheat pipe methanator designs would not even be considered. The main disadvantage of

using mercury arises from its toxicity. Although stainless steel-mercury heat pipes are expected to be extremely durable at temperatures much higher than those required for methanation, the consequences of escape of even small quantities into the atmosphere or into the pipeline are such, particularly from a public reaction viewpoint, that the worst possible situation should be anticipated. Detection equipment with short response time and trapping systems for handling the worst-case situation would have to be installed.

Although cesium and potassium are marginal heat transfer fluids for the methanator application, their advantage from a standpoint of stability and lack of toxicity are such that they should be retained as potential selections and thoroughly evaluated for cost effectiveness. Their use will favor larger heat pipe surface area to vapor flow passage area ratios (i.e., larger diameter heat pipes), which will result in a reduction of the catalyst surface area per unit volume in the methanator pressure shell. Because the vapor pressures of these two substances will be very low, even at the high end of the methanation reaction temperature range, adequate control of hydrogen influx into the heat pipes (see Sec. IV.B) will be more crucial than for Dowtherm A or the mercury working fluid.

The above list of heat pipe working fluids has been restricted to materials that are now commercially available. There is some expectation that fluids now being developed will demonstrate a higher degree of thermal stability than Dowtherm A. Further, a thorough search for high-temperature organic materials suitable for heat pipe application apparently has not been made. This is particularly true for materials whose melting points are well above ambient temperature but lower than about 575 K. Such materials would not be considered as heat transfer fluids for normal applications because freezing would be a problem. However, in high-temperature heat pipe design, materials that are solid at ambient temperature, including silver and copper, are used without difficulty.

IV. OTHER DESIGN CONSIDERATIONS

A. Heat Exchanger Gap Sizing

Reliance on gas gaps for thermal coupling between the individual heat pipes and the interior thimble walls of the heat exchanger end plate is the feature that gives the heat pipe methanator design the ease of catalyst changeability and lack of requirement for high-pressure feedthroughs for individual tubes. As indicated earlier, the gap size

depends on such obvious parameters as the desired ΔT , the length and diameter of the thimbles, and the amount of heat flow transmitted per heat pipe. More importantly, the gap size depends on the conductivity of the gas in the gap. This presents the difficulty of determining the steady-state composition of this gas mixture. It is assumed that the initial mixture will be $3\text{H}_2 + \text{CO}$. Here the thermal conductivity of the mixture will be 65% of that of hydrogen or 200 MW/m K at 650 K. If the desired ΔT is taken to be 35 K, the heat exchanger thimbles to be 2.0 m long and 51-mm i.d., and the heat transport per heat pipe to be 11.4 kW, then the gap size is 0.2 mm. Should the $3\text{H}_2 + \text{CO}$ mixture convert to $\text{CH}_4 + \text{H}_2\text{O}$ in the gap, the resulting thermal conductivity would be about 40% of that of the initial mixture, calling either for a gap size of 0.08 mm (3 mils), a higher ΔT , or an increased gas gap surface area. It is anticipated that the gas gap will be a problem only if the formation of solids occurs, preventing the easy removability of the heat pipes from the thimbles. Presumably the whole question of reactions in the gap could be avoided by coating the thimble and heat pipe surfaces with non-catalytic materials.

The gap size estimates made here assume a constant ΔT across the gap. Because the water temperature in the heat exchanger will increase by about 300 K as it flows from the region at the ends of the heat pipes toward the methanator-heat exchanger end plate, the final design will probably have a tapered gap to make the heat flux more uniform, and the gap will be considerably larger than indicated above for much of its length. The configuration and amount of taper at the ends of the heat pipes must be determined by detailed heat exchanger design analysis, which incorporates the effect of axial variations in vapor condensation rate on heat pipe performance and the desired change in heat transfer rate vs the axial location of the vapor-gas interface, as discussed in the previous section. The gap configuration will probably take the general form shown in Fig. 5, where the vertical scale has been greatly magnified relative to the horizontal scale.

B. Hydrogen Diffusion

Hydrogen diffusion through the heat pipe wall is a problem of major importance to the heat pipe methanator design. At 672 K (750°F), the permeation rate for hydrogen through 304 stainless steel is $5.0 \times 10^{-3} \text{ cm}^3 \text{ STP mm/h cm}^2 \text{ atm}^{1/2}$. Thus the permeation rate into a heat pipe 11 m in length, 51 mm in diameter, and with a 2-mm wall thickness will be 119 mm³/s (26 in.³/h) for a hydrogen partial

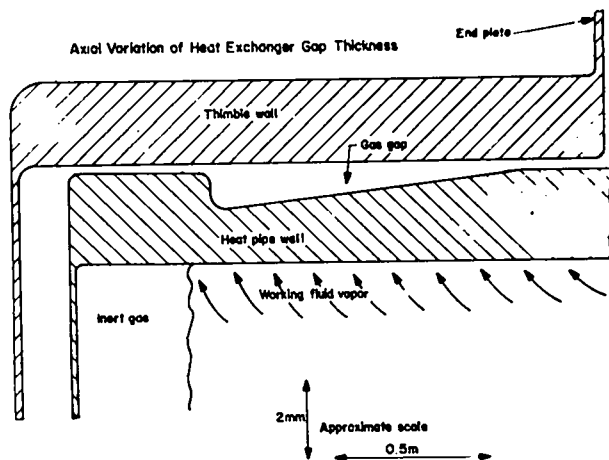


Fig. 5.

General configuration of heat pipe to thimble wall gap. Scale is approximate (note difference in vertical and horizontal scales).

pressure of 5.2 MPa (750 psi). The heat pipe will initially have an ~ 0.5 -m-long section filled with inert gas which, for this operating temperature with Dowtherm A working fluid, will be at a pressure of 10.4 atm. The hydrogen influx will then cause this pressure to double in ~ 11 h, causing the operating temperature to rise to 732 K (858°F). This rate is obviously intolerable.

The three potential methods for dealing with the hydrogen influx problem are (1) introducing a low permeability layer into the heat pipe wall, (2) putting a hydrogen getter material into the inert gas section of the heat pipe, and (3) venting the hydrogen continuously. The last method eliminates the complete heat pipe containment feature of the reference design. This is discussed more fully in Sec. IV.E.

Introducing a low permeability layer such as aluminum onto or into the heat pipe wall can markedly reduce the hydrogen influx. For aluminum, a 1-mm layer would decrease permeation by a factor of 1260 and make a scheme whereby the heat pipe control gas was changed when the catalyst was changed a feasible operating method.

The extrapolation to 672 K of data taken at temperatures above 800 K on the diffusion of hydrogen through thin liquid lead barriers⁶ indicates that a 0.5-mm-thick lead layer would be at least 100 times as effective as a 1-mm-thick aluminum layer in reducing hydrogen diffusion. A barrier with this degree of effectiveness would eliminate the problem of hydrogen diffusion.

Because a hydrogen volume influx rate of 119 mm³/s STP corresponds to a mass influx rate of only 10.7 $\mu\text{g/s}$, adding a hydrogen getter such as zirconium to the heat pipe is another potential method

for controlling hydrogen influx. Absorbing the hydrogen entering the heat pipe in 3000 h by the formation of ZrH_2 would require an initial charge of approximately $3 \times 10^5 \text{ mm}^3$ (18 in.³) of zirconium. Possibly, a combination of impermeable coatings and a hydrogen getter would represent the best solution to the hydrogen influx problem, and could stretch the time interval for heat pipe servicing to several years.

C. Working Fluid Degradation

Degradation of potential heat pipe working fluids for the methanator application is a problem only for Dowtherm A. Although this appears to be the most stable material of the commercially available high-temperature organic cooling fluids, its degradation rate in the temperature range required for the methanation reaction is sufficiently high to constitute a problem in the closed system heat pipe methanator design. Figure 6 shows this degradation rate as a function of temperature.⁷ The decomposition products are primarily higher molecular weight organics, which in small quantities are not expected to have an appreciable effect on heat pipe operation. However, it is anticipated that ~1 wt% of the decomposition products will be hydrogen. Therefore, for an initial heat pipe loading of $3 \times 10^6 \text{ mm}^3$ (183 in.³) of Dowtherm A, ~0.7 g of hydrogen will be generated in 3000 h at 644 K (700°F). This is ~1% that would diffuse into a stainless steel heat pipe with a 2-mm-thick wall. However, for decomposition, the hydrogen is formed within the heat pipe, therefore it must be accommodated by either gettering or continuous venting.

The high boiling point decomposition products produced in one year's operation at 644 K represent 7.2% of the initial charge of Dowtherm A. If Dowtherm A is used as the heat pipe working fluid, provision must be made to replace the Dowtherm A periodically. How frequently this must be done can only be determined experimentally, but the fluid replacement interval may be considerably longer than that for catalyst replacement. Designing the heat pipe with a removable end cap for easy change-out of fluid does not appear to be a difficult problem because the heat exchanger end of the pipe will be at low temperature. Nevertheless, organic working fluid materials more resistant to thermal degradation should be investigated in an effort to lengthen the heat pipe maintenance interval.

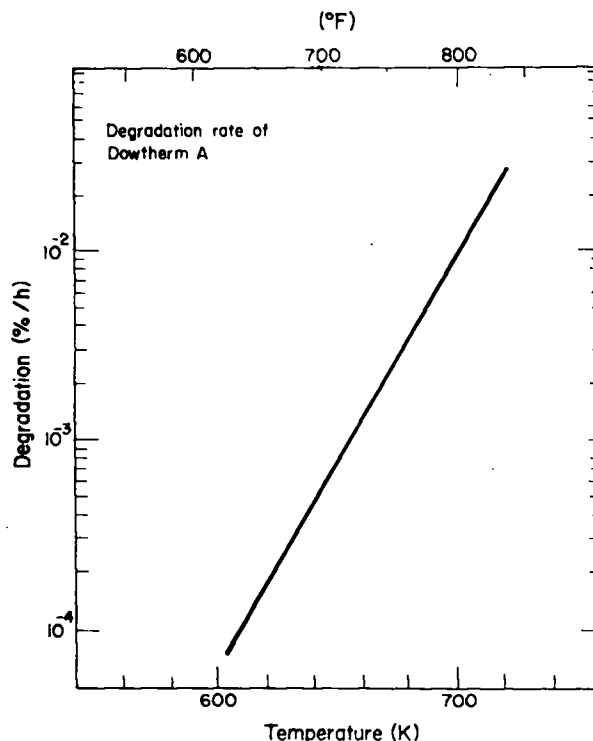


Fig. 6.
Degradation rate of Dowtherm A as a function of temperature. Degradation products are mainly higher boiling point liquids.

D. Catalyst Application

As indicated earlier, direct contact of the methanation-promoting catalyst with heat removal surfaces is necessary to prevent the formation of hot spots and consequent catalyst poisoning. Therefore, flame spraying of Raney nickel is preferred because it assures excellent thermal contact. PERC investigators have found that removing the deteriorated catalyst by sandblasting is a relatively simple and effective step in the catalyst renewal process.⁸ Although flame spraying and sandblasting appear to be viable solutions to the catalyst change problem (at least for external surfaces), it is conceivable that faster and more economical methods can be developed.

As a guideline to the search for other application methods, note that although direct thermal contact is desired, it does not have to be as direct as that obtained by flame spraying. This is because the heat flux through a thin catalyst layer to the heat removal surface is limited to a relatively low value by the methanation reaction rate (~13 kW/m²). Therefore, gas coupling can be used as long as the effective gas path is limited to about 0.5 mm. An alternative method for applying the Raney nickel catalyst to the

external surface of the heat pipe would be to spread a 1- to 2-mm-thick layer of catalyst particles on a relatively coarse mesh screen with an organic binder to hold the particles in place. The screen could then be wrapped around the heat pipe, possibly swaged, then spot welded, crimped, or otherwise fastened in place. The binder could then be removed by heating the unit to a relatively low temperature, depending on the binder used. This method appears amenable to developing a high-speed, low-cost means of applying catalyst. It would also have the advantage of easy catalyst removability because sticking of the catalyst to the heat pipe wall is improbable at the temperature reached in the methanation reaction.

It is also conceivable that thin wall tubes of catalyst having the required porosity could be formed by an extrusion process so that a number of short lengths could be slip-fit over the heat pipe. This would make catalyst replacement a very simple process, but the feasibility of forming catalyst tubes with the required strength, porosity, and dimensional tolerances requires a more in-depth investigation.

E. Continuous Venting Design Option

Because the control of hydrogen influx into the heat pipes of the heat pipe methanator unit is the most severe design problem likely to be encountered, consideration has been given to the nature of continuous venting designs as a back-up to the fully enclosed system described above. At first sight, continuous venting appears to bring back all the difficulties of requiring separate high-pressure flanges for each tubular component of the methanator—the difficulties which caused the PERC investigators to shift from tubes externally coated with catalyst to internally coated tubes. However, the use of continuously vented heat pipes allows the high-pressure fittings to be very small and less prone to leakage. Further, there is no problem with available space in the end plate, and if leaks do occur, it will be much simpler to pinpoint their location and correct the difficulty.

The manner in which continuous venting can be achieved is shown in Fig. 7. Small diameter tubes are welded into each pipe, extending from the right-hand end of the heat pipes to the inert gas region at the other end. This is done so that the required high-pressure feedthrough fittings will be located in the end plate opposite the thimbled heat exchanger end plate. Otherwise a double-sealed system would be required, pinpoint leak detection during operation would be impossible, and assembly would be much more complicated.

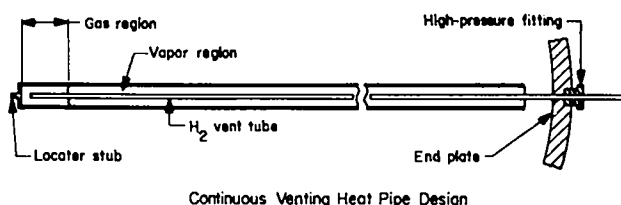


Fig. 7.

Heat pipe design option for continuous venting operation. Relative size of central tube can be much smaller than shown.

In operation, excess gas accumulating in the inert gas section of each heat pipe is bled off through the vent tubes to a common pressure regulating system. Because the gas overpressure determines the heat pipe operating temperature, a system of this type enables the latter to be continuously monitored and changed, if desired.

Proper design of the end plate should make the installation of the bleed tubes a relatively simple matter because the heat pipes will be free to slide back and forth during the assembly sequence. The high-pressure feedthrough fittings and the fittings used to connect the bleed tubes to the master pressure regulating system must be designed so that the tubes are free to slide through the holes in the end plate during disassembly.

F. Start-up Methods

For the methanation reaction to proceed, the incoming gas must be heated to about 644 K (700°F). During operation this is accomplished in the preheat section, as discussed previously. Because some of the heat from the methanation reaction is used for the preheat operation, it is obvious that the system is not self-starting, i.e., heat must be applied to bring the initial charge of gas up to operating temperature before self-sustaining operation can begin.

One method of applying start-up heat is to install a separate preheat unit into the inlet gas line and slowly introduce the hot gas into the methanator unit to bring it up to the temperature of self-operation. An alternative method is to design the right-hand end plate to have a thimbled configuration similar to that of the heat exchanger end plate (see Fig. 1). This is shown in Fig. 8. With this arrangement, either hot gases from a methane burner or electrical strip heaters can be used to heat the heat pipes directly and in turn heat the charge of gas contained in the methanator unit. The latter would initially be stagnant hydrogen to which carbon monoxide would be

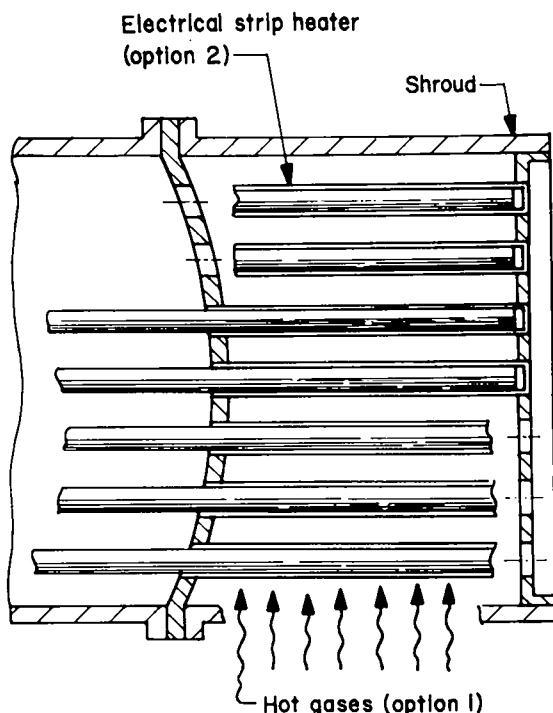


Fig. 8.

Methanator design option with thimble heat exchanger to permit rapid startup. The cover shroud will insulate the start-up section during operation. Start-up heat is furnished by a gas burner (option 1) or by electrical type heaters (option 2).

added when the self-operating temperature of the unit was reached. Once self-operation was attained, a cover shroud could be placed over the thimble array to reduce heat loss by radiation and convection.

This arrangement for furnishing preheat for start-up does not preclude the use of continuous hydrogen venting, should it prove necessary, because the high-pressure bleed tube fittings can be installed in the ends of the thimbles, and only minimal complication of the assembly sequence need result. The cover shroud can be designed so that the fittings are observable during operation since the heat loss from the thimble ends will be negligible.

V. DESIGN ALTERNATIVES

The heat pipe methanator design and design options discussed above use circular cross-section heat

pipes for simplicity of manufacture and suitability for high-pressure applications. However, this is not the only possible configuration because the thimbles, as well as the heat pipes, could be made in various cross sections. In particular, flat plate heat pipes represent a means of introducing more surface area per unit volume, although they would require external bracing on the thimble walls and internal bracing in the heat pipes. However, with a flat plate configuration it is possible to spread catalyst particles between the heat pipes in an array easily assembled outside the methanator pressure shell with the entire assembly then being inserted into the pressure shell as a unit. Such an array would simplify the catalyst renewal procedure and might promote more efficient catalyst utilization. It is doubtful that movement of the catalyst particles by the gas stream would be a significant problem in such a design, because typical flow velocities—as limited by the methanation reaction rate—are less than 1 m/s.

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